US ARMY TEST & EVALUATION COMMAND

JUNGLE VISION

II: Effects of Distance, Horizontal Placement, and Site on Personnel Detection in an Evergreen Rainforest.

US ARMY
TROPIC TEST CENTER
FORT CLAYTON, CANAL ZONE

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II: Effects of Distance, Horizontal Placement, and Site on Personnel Detection in an Evergreen Rainforest.

by

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US Army Tropic Test Center
Fort Clayton, Canal Zone

November 1964

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Unclassified

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3. Visual Threshold
4. Tropics
5. Human Factors Engineering

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FOREWORD

The present report is the second of a Tropic Test Center series dealing with personnel detection in tropical forests. This research is supported by the US Army In-House Laboratory Independent Research program.

The primary purpose of these studies is to provide a baseline of quantitatively sound data concerning the visual capabilities of the soldier in the jungle. From the standpoint of the Test and Evaluation mission of the Center, these data afford a backdrop against which technological extensions of the human eye may be evaluated. Additionally, the technique for measurement of visual thresholds is also applicable to the testing of visual performance aids. The Tropic Test Center, because of its geographical location, is ideally situated to collect these basic data on the tropical environment that are of military interest.

Beyond the application to the Center's Test and Evaluation mission, however, these reports may have implications for tactics, training, operations, and development requirements. For these reasons, the reports are given a wide distribution.

The authors gratefully acknowledge the efforts expended by the following Tropic Test Center personnel:

Charles M. Kindick
SFC Frank J. Muscutt
Ricardo Ah Chu
Vernita George
Carolyn Corn

BRIEF OF RESULTS

Thirty enlisted men from an Artillery unit in the Canal Zone, preselected for normal vision, were each presented forty uniformed human targets (stationary, standing, and facing the observer) at three evergreen rainforest sites on the north side of the Canal Zone during October and November 1964, during the rainiest period of the wet season. The targets appeared at eight distances--40 to 100 feet--and were randomly presented along five radii separated at 30° intervals across a search area of 180°. The observer, denied the aid of auditory cues, pointed to the target when detected and estimated its distance. Levels of illumination and time to detect targets were also recorded. The results were as follows:

1. The overall detection threshold (point of 50% detectability) for the three sites combined was 72.6 feet. The three sites did not differ significantly with respect to overall threshold values. Horizontal target placement did not affect target detectability within the 120° angle encompassed by the five radii. The greatest deterrents to vision appeared to be the extremely low levels of illumination, caused by the dense forest canopy, as well as the low-branching palms and the large-leafed herbaceous plants typical of the undergrowth of the evergreen rainforest.

2. Ninety-five percent of the targets presented at the 40-feet distance were detected; only 10 percent of the targets presented at the 100-feet distance were detected. Thus, a distance of only 60 feet made the difference between nearly perfect and nearly impossible target detectability. The function relating detection probability to target distance was linear.

3. Observers consistently underestimated true target distances on the average of 11 feet. There was only a slight tendency for range estimates to become more variable from observer to observer as true target distance increased.

4. Detection time increased as target distance increased. For example, target detection required nearly three times longer at 100 feet (62 seconds) than at 40 feet (22 seconds).

5. All sites were characterized by extremely low illumination levels--typically ranging from only 4 to 17 foot-candles. A statistically significant relationship was found between detection thresholds of individual observers and illumination levels at their test sites.

6. Individual observer thresholds within the sites did not vary greatly. Individual thresholds varied to approximately the same extent within sites as did average thresholds among the three different sites.

7. Detection thresholds were statistically independent of the age of observer or length of service in the Army within the ranges of the present study.

8. There was no evidence that detection performance improved through practice during the course of 40 observations per observer.

9. Selected comparisons were made between the present study and a similar previous study conducted in a tropical semideciduous forest on the south side of the Canal Zone during the dry season as follows:

a. Difficulty of target detection did not differ significantly between the two types of forests when difficulty is defined in terms of 50% detection thresholds. Intraforest variability of detection thresholds was greater than interforest variability, thus the vegetative labels presently applied may not be useful with respect to average detection difficulty or variability.

b. Detection probability functions, however, differed substantially. That for the evergreen rainforest was linear--for the semideciduous forest S-shaped (ogival). Even though the 50% thresholds did not differ significantly, target detection between the 65 and 100 feet range was much more difficult in the semideciduous forest.

c. The results of the two studies strongly indicate that the absolute limit of personnel detection--under the conditions of these studies--lies in the 100 to 110 feet range in both types of typical tropical vegetation.

d. Evidence was presented which indicated that illumination plays a greater inhibitory role to visibility in the evergreen rainforest than eye-level vegetation within the evergreen rainforest, however, there is no direct evidence to support this contention.

e. Individual observer variation in detection thresholds are sufficiently small to allow small site means to represent larger geographic areas with fairly high accuracy.

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Qualified requestors may obtain copies of this report from the Defense Documentation Center.

INTRODUCTION

Little quantitative data are available on visual thresholds in tropical forests. Even though a series of magnification, night vision, and ranging aids have been developed for use in remote area operations, quantitative statements concerning unaided detection are sparse. To fill in the gaps, the US Army Tropic Test Center has initiated a series of studies to establish visual thresholds in different types of tropical forests, using the most probable jungle targets (uniformed soldiers) and representative observers*, with strict experimental control over procedure. The present report is the second of this series. The first report, Jungle Vision I, established thresholds in a semideciduous tropical forest during the dry season; the present report is a replication of the first, accomplished in an evergreen rainforest during the wet season.

BACKGROUND

Prior to the Tropic Test Center studies, only one quantitative determination of target detectability in tropical forests was found in the scientific literature. The study was performed by the US Army Natick Laboratories in 1963 (1)**. In this study, the maximum ranges for detection of human targets in a semideciduous forest was between 35 and 55 feet.

In the Tropic Test Center's first study, Jungle Vision I (5), conducted in March 1964, 30 Infantry observers with normal vision were presented 40 randomly appearing targets in a 180-degree field of search at three different sites. Detection thresholds averaged approximately 60 feet. Average detection thresholds for the easiest site was 70.3 feet; for the most difficult site, 52.2 feet. Statistically significant site differences were noted. One hundred feet approximated the limits of target detectability. The primary deterrent to visibility was the dense network of low hanging small vines and lower shrubs. Within the ranges investigated, horizontal target placement, age of observers, length of military service, immediate practice, and prevailing levels of ambient illumination had little or no effect on target detection.

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* Troop observers were provided through the assistance of the Chief, Combat Developments Office, US Army Forces Southern Command, and the Commanding Officer, 4th Missile Battalion (HAWK-AW), 517th Artillery.

** See Bibliography.

OBJECTIVES

The objectives of the present study were as follows:

a. To determine detectability of uniformed human targets in the evergreen rainforest during the wet season.

b. To compare the results with those of a similar previous study performed in the semideciduous tropical forest during the dry season.

c. To continue accumulation of data useful as control information for the evaluation of technological aids to jungle vision.

METHOD

Observers. Thirty observers (O's) were tested. Observers were drawn from the 4th Missile Battalion (HAWK-AW), 517th Artillery, stationed at Fort Sherman and Fort Davis in the Canal Zone. Fifteen O's were in Combat MOS (e.g., Launcher Crewmen, Cannoneers); the remainder were in Support MOS (e.g., Missile Mechanics, Radio Repairmen). Observers' ages ranged from 18 to 35 years; the mean age was 22.4 years. Grades ranged from E2 to E5; most were in grades E2 and E3. Amount of time in the service ranged from 6 to 192 months; the average time was 34.1 months. Each O was pretested with an Ortho-Rater vision tester to insure normal close, distance, and color vision, as well as depth perception. From the initially selected pool of thirty O's, three subgroups, comparable in visual acuity, were randomly assigned to one of the three different sites for testing.

Targets. Targets were two US Army soldiers dressed in standard utility (fatigue OG-107) uniform without insignia, including jacket, cap, bloused trousers, and jungle boots. Both targets were 6' 1" in height; one weighed 185 lbs; the other weighed 160 lbs. (The same individuals served as targets in the previous Tropic Test Center study, Jungle Vision I.) No web equipment or firearms were worn. The targets, their faces blackened with charcoal, stood motionless on predetermined marked positions facing the O (see Figure 1). The same targets were used throughout the experiment.

Experimenter. One experimenter (E) was present during testing. (The same E had participated in Jungle Vision I.) E's prior experience, coupled with the fact that the "targets"

were also experienced from the previous study, made it unnecessary to have a second experimenter to deploy targets, as was the case during Jungle Vision I. The E gave all instructions to the O's, scored detections, and recorded range estimations and detection times.

Figure 1. Close-up view of target.

Independent Variables. Three independent variables were investigated: target distance, horizontal target placement in O's field of search, and test site.

(1) Target Distance. Eight distances were used: 40, 50, 55, 60, 65, 70, 80, and 100 feet. These distances were selected on the basis of preliminary studies which indicated that most targets were seen at 40 feet and few at 100 feet. Five-feet increments were used between the 50 to 70 feet distances because the preliminary studies also indicated that the average threshold was more likely to fall within this range. Smaller increments near threshold values ensure a more precise threshold.

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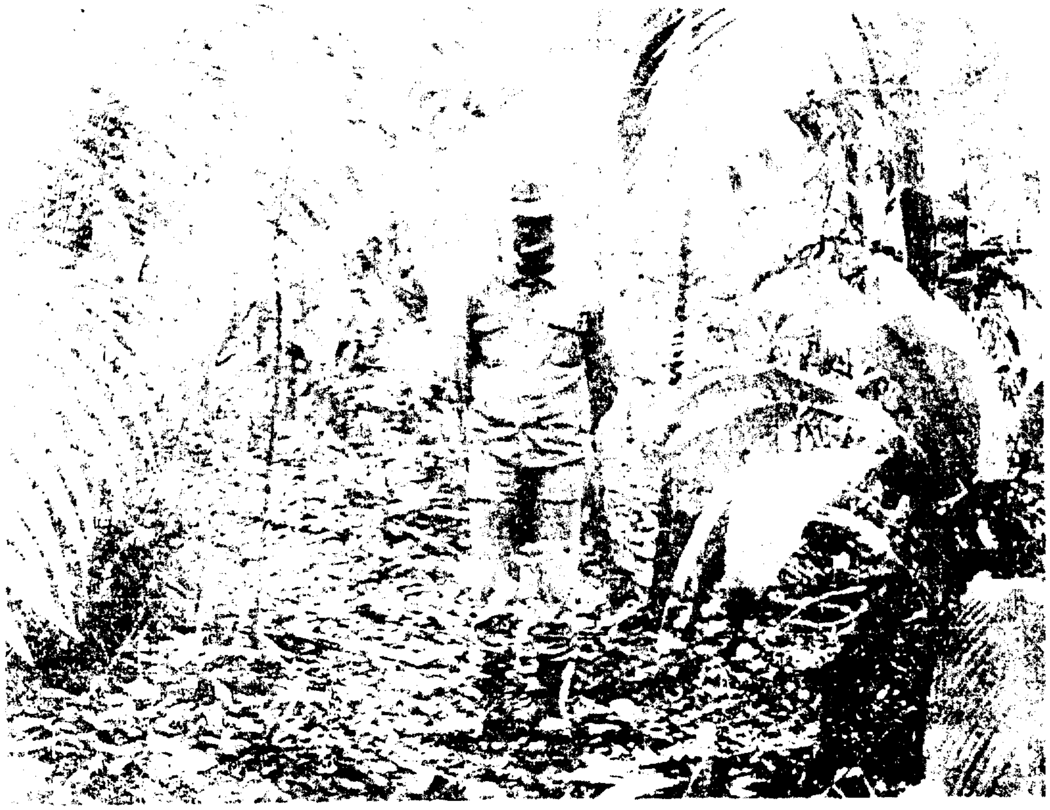

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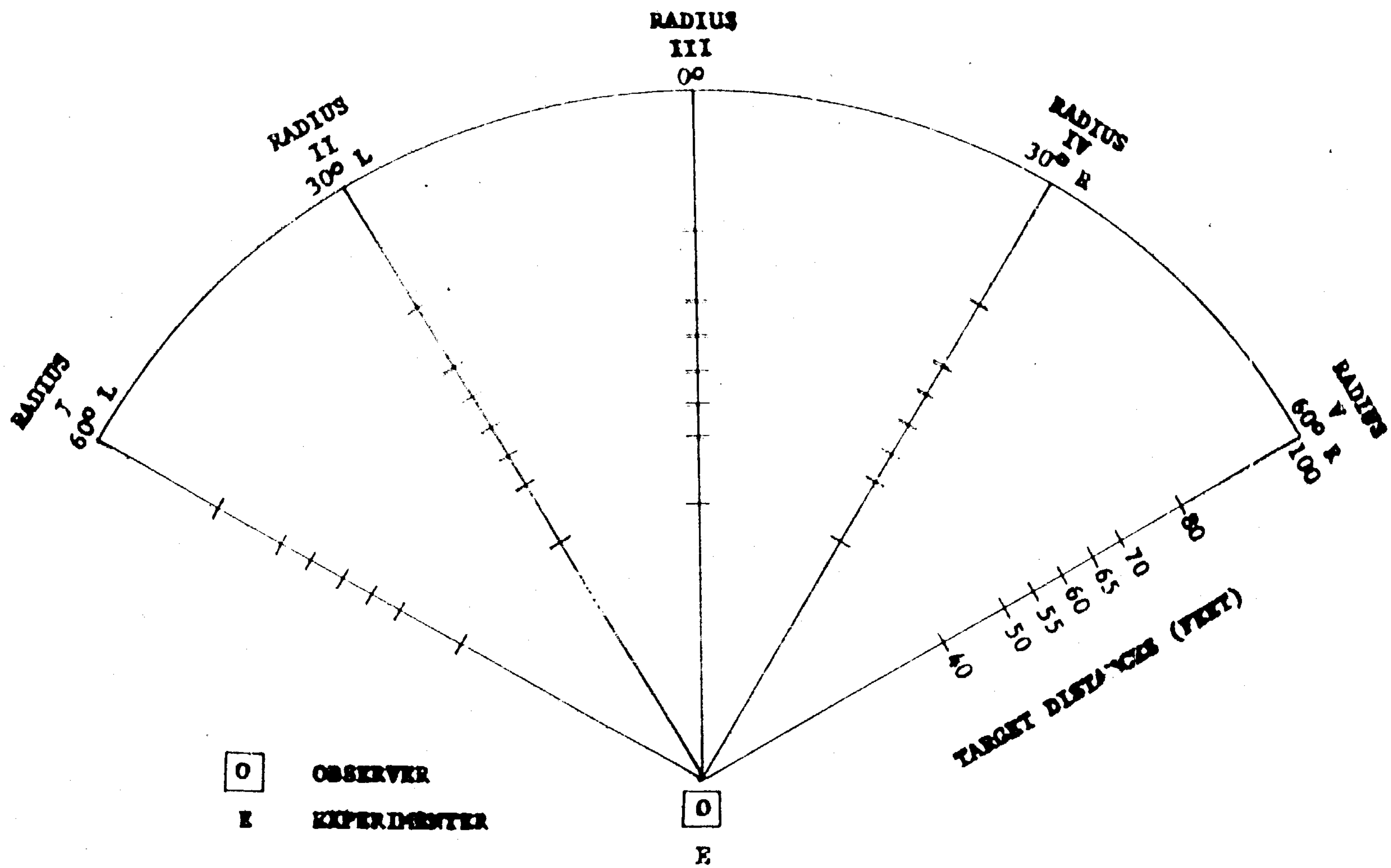

FIGURE 2. SKETCH OF TEST SITE SHOWING TARGET DISTANCES AND PLACEMENT

(2) Horizontal Target Placement. The O's field of search was 180°. All targets were actually within a 120° field, but O's were not aware of this. Five 100-feet radii extended outward from the O's fixed position (Figure 2). Radius I was 60° to the left of the O's line of sight, II was 30° left, III was in the direct line of sight (12 O'Clock), IV was 30° to the right, and V was 60° to the right. There was one deviation from this fixed pattern in the present study. On Site X, Radius II was 45° left rather than 30° to avoid a large, buttressed tree.

(3) Site Selection. Three sites were selected, adjoining road number S-1 within the Fort Sherman Military Reservation. Sites X and Y were situated near to each other, approximately five miles northwest of the intersection of roads S-10 and S-1. Site Z was situated approximately 100 yards southeast of the intersections of roads S-8 and S-1.

Sites were selected to meet the following criteria:

a. To be apparently representative of the vegetation of the larger evergreen rainforest of which they were a part.

b. To be relatively level to prevent physical terrain features from hindering vision.

c. To allow the radii to be laid out in such a manner that targets would not be completely hidden behind large tree trunks. Since there are many large trees in the evergreen forest, this fact should be kept in mind when interpreting results.

The objective of site replication was to obtain an estimate of intraforest variability with respect to target detectability. Intraforest and interforest variability for Jungle Vision studies I and II are discussed on page 22 of this report.

Description of Sites. The sites used for this study represented an evergreen rainforest in advanced stage of growth. Overlapping crowns in the upper stories had caused the elimination of nearly all plants on the forest floor except those extremely tolerant of shade. Unlike the sites described in Jungle Vision I, which had a dense, tangled undergrowth difficult to walk through without the aid of a machete, the vegetation of the rainforest sites was easy to walk through. It was not necessary to cut paths to allow the targets to reach their

positions, nor was trampling of vegetation a problem as at Jungle Vision I sites. Plants with single stems comprised most of the undergrowth; and the numerous tiny vines that tied the undergrowth together in the semideciduous forest were lacking. Even when the sun was bright in the open, deep shade prevailed in the rainforest. In contrast to the semideciduous forest, where ambient morning light levels of more than 100 foot-candles were common, morning light levels as low as one foot-candle were recorded during the present study. Only small shafts of light ever reach the floor of the rainforest. The present study was conducted during October and November, near the end of and during the rainiest part of the wet season, when the vegetative cover was at its maximum and sunlight almost completely screened out. In the semideciduous forest, the sun flecks on the leaves of the many vines had a dappling effect on the targets and vegetation, thus reducing visual contrast. The dappling effect in the semideciduous forest was sometimes enhanced when there was a breeze. Under the rainforest canopy a measurable wind is rare.

(1) Site X (See Figure 3a at end of report). For the most part, the ground at this site was fairly flat; however, there was a slight slope downward along Radius V and about a 10% slope upward from 70 to 100 feet along Radius II. Neither of these slopes obscured the target image. The light brown clay loam soil was covered with a very thin mat of decomposed leaves.

Towering over the site, the upper story of the canopy reached approximately 125 feet. This site was the darkest of the three; illumination levels were only one-half as high as the other sites (See Tables VIII and IX). Columnar trunks of the trees in this story were free of branches for nearly 90 feet, but some of the boles were encircled by vines as much as six inches in diameter. Leaves on these vines broke the outline of the trunks, which generally ranged from 15 to 30 inches in diameter. Buttresses added another dimension to the trunks. Extending outward for almost five feet in some cases, the buttresses ringed a few trees as high as six feet up the trunk; most of the buttresses started about three feet up the trunk. Wild fig trees (Ficus glabrata) were the most conspicuous of the species in the upper story.

Beneath the upper story at heights ranging from 40 to 80 feet was the second layer of the canopy, comprising trees whose trunks were only five to eight inches in diameter. Stilt palms (Socrates durissima) were the most prevalent of the species at this level. Balanced on prop roots that form a base for the tree, the trunk of the stilt palm does not touch the ground; some of the trunks began at heights of six to eight feet. All of the trees in the second story branched only at their tops and, except for the numerous prop roots of the stilt palms, did not affect the horizontal visibility of standing targets. Their crowns, however, generally closed the gaps in the upper story and contributed greatly to the reduced illumination levels at the forest floor.

A third layer of vegetation at this site was composed of trees two to four inches in diameter and 10 to 25 feet high. These trees extended toward the shafts of light that filtered through the upper two stories. Stilt palms and maquengue palms (Oenocarpus panamanus) were numerous, but there were many woody trees, including Desmopsis panamensis and Xylopia macrantha. Except for the multiplicity of stems, the trees in this layer did not hamper ground observation.

By far the greatest obstacle to visibility at ground level was a species of palm (Geonoma decurrens), which has leaves that are as long as three feet and as wide as one foot. Most of these plants were from four to seven feet tall, and the leaves were very effective in breaking the outline of a standing human figure.

Interspersed through the undergrowth were spiny black palms and a variety of thin-stemmed herbaceous plants; these were mostly between three and five feet tall.

Although the underbrush appeared fairly dense, it provided little hindrance to movement on foot because stems were several feet apart.

(2) Site Y (See Figure 3b at end of report). The light brown clay loam soil at this site was eroded into numerous shallow gullies, one of which is evident on the left side of Figure 3b. Leaf litter was even less thick here than at Site X even though the sites were very close. There was no noticeable slope to the ground.

Wild fig (Ficus glabrata) and copal (Protium panamensis) were among the trees forming the upper story at this site. At heights of 100 to 125 feet, the crowns of these thick-trunked trees provided almost a complete canopy over the site. The lower branches of the wide-spread crowns contained many

epiphytic and parasitic plants, and the columnar trunks were encircled by thin vines. Some of these vines had large leaves that have the shape of elephant ears. Except to contribute to the deep shade at the floor of the jungle, the trees in the upper layer did not hamper target detection.

As at Site X, stilt palms made up the bulk of the trees in the second story, though they were not as numerous. Characteristically, nearly all of the trees in the 40 to 80 feet height category were situated beneath holes in the top canopy where the trees could receive some sunlight. Although they were fairly tall, the trees rarely had trunks more than six inches in diameter.

In the layer from 10 to 25 feet, the different types of palms were most easily recognized. Stilt, wide-leaf, black, and maquengue palms were the principal varieties. Stems of these palms, as well as of the woody plants at the site, were usually not more than three inches in diameter. For the most part, the leaves of the trees in this layer were above eye level, but some of the larger leaves did hang far enough to hinder horizontal visibility of standing targets.

The underbrush at this site was composed of relatively few plants. Because of their leaf structure, however, they occupied a great deal of space. Wide-leaf palms and maquengue palms were the most formidable hindrances to ground observation. The maquengue, with its 10-feet long, multileaf branches, practically hid a person from view. (Features of the wide-leaf palms were discussed under Site X.) In addition to the palms, a herbaceous plant (Stromanthe lutea), with large leaves growing in clumps at the end of long stems, was present in quantity.

(3) Site Z (See Figure 3c at end of report). The ground at this site was flat, with the micro-relief rarely exceeding six inches. A one-inch mat of dried leaves covered the brown clay loam soil.

Although a few trees at this site reached heights of 125 feet, the general level of the upper story was about 100 feet. At this level, the overlapping crowns formed a very dense canopy over the site. Most of the trees were a variety of palm (Scheelea zonensis), but there were some hardwoods scattered through the site. Trunk diameters ranged from 15 to 20 inches for the taller trees to 10 to 12 inches for those forming the principal canopy.

Beneath the top layer, the trees formed a discontinuous pattern at heights from about 20 to 60 feet. Most of these smaller trees were different types of broadleaf evergreens mixed with some young palms. For the most part, boles were between three and six inches in diameter, with an occasional tree as much as eight inches. The few vines generally were wrapped around the thin trunks and did not extend from tree to tree. Because nearly all of these trees branched only at their tops, the trees had relatively little effect on horizontal visibility.

The undergrowth in the deep shade of the forest floor was quite sparse. An herbaceous plant with long thick leaves (Stromanthe lutea) was the most prevalent species. In contrast to Sites X and Y, wide-leaf palms (Geonoma decurrens) were scarce at this site. Other palms were plentiful, however, particularly several varieties of spiny black palm (Bactris sp. and Astrocaryum sp.) and the panama hat palm (Carludovia palmata). Most of the plants were between four and eight feet tall and had slender, supple stems. A single leaf extended outward from the end of each of the many branches. These leaves were the principal camouflage at this site at ground level.

Dependent Variables. Three performance measures were used. The first measure was the detection threshold. The threshold is defined as that distance at which a target is detected 50% of the time.

The method used to establish detection thresholds in the present study has no exact counterpart in the classical psychophysical methods of the laboratory. The method resembles that of "constant stimuli" with respect to randomization of stimulus magnitudes (target distances); however, randomization with respect to horizontal placement is only partial since stimuli could appear only on five predetermined radii. With respect to the use of radii along which stimulus magnitudes could be systematically increased or diminished in small increments, the present method bore some resemblance to the "limits" technique. It is sufficient to note that certain aspects of both techniques are in evidence. It is more important to note that target position and distance were not predictable from trial to trial, thus making it unlikely that O's could build up systematic biases of expectation or habituation.

The second performance measure was distance estimation. For those targets which were detected, each O was asked to estimate the distance. The primary purpose of this measure was to determine the accuracy of estimating target distances and, more specifically, to determine whether there is a

constant error involved in distance estimation in the evergreen rainforest.

The third performance measure was detection time. For those targets which were detected, search time was recorded with a stopwatch.

Research Design. The research design is summarized in Table I. Three separate subgroups of 10 O's each, comparable in visual acuity, were assigned randomly to each of the three sites. Each O was presented 40 targets which appeared randomly with respect to distance and horizontal placement. Each of the eight distances appeared an equal number of times across all five radii. Each of 10 O s was presented eight targets per radius, making a total of 400 observations per site, or 1200 observations in all. Target sequence was randomized across radii and distance by a table of random numbers (Appendix A).

TABLE I

Research Design of Jungle Vision II

		Radius					
		I	II	III	IV	V	
Site	Number Observers	Number Observations (n)					Total (n)
X	N=10	80	80	80	80	80	400
Y	N=10	80	80	80	80	80	400
Z	N=10	80	80	80	80	80	400
Total	N=30	240	240	240	240	240	1200

Procedure. Test sites were laid out according to Figure 2. Illumination measures were taken at the O's eye and at the midpoint of each radius with a GE type 213 light meter before and after testing. All sites were laid out approximately north-south to minimize the effect of sunlight on O's vision.

The O's were tested one at a time (See Figure 4). The O was informed by E, reading from a standardized set of instructions, that this was a test of his ability to spot targets in a jungle environment. The O was informed that targets would appear at any point from nine o'clock to three o'clock (180^{o}). The O was informed that he had two minutes to make a detection; if at the end of that time he had not detected

a target, it was scored as a nondetection. The O was fitted with HEAR-GUARD model 1200 ear protectors to reduce the possibility of responding to auditory cues caused by movements of the targets through the vegetation. The O was urged to guess when he was unsure of the location of the target. (See detailed instructions to O's in Appendix C.)

Before the appearance of the first target, E turned O around facing away from the course. E blew a whistle signalling one target into the first position. The target took his place on a given radius at a pre-emplaced distance marker and stood immobile, facing the O. The target returned a whistle signal informing E that he was in position.

Figure 4. Experimenter and Observer.

The O was confined to a marked three-feet square. He was allowed to bend, twist, crouch, or lie down in searching for targets but was not allowed to move his head outside the marked square.

The O was required to point and give a distance estimate when he detected a target (See Figure 5). O was not informed as to the correctness of his detection. After the first trial, E again turned the O around and signalled the target to return to the 100-feet distance (out of sight). This was also the cue for the other target to assume the next position. The above sequence was repeated until O completed 40 observations. Total testing time for one O ranged from one to one and one-half hours. One rest pause of five minutes was allowed after the 20th trial. (Three rest pauses of three minutes each were allowed during Jungle Vision I; the procedure was changed during the present study because O's felt that three pauses were unnecessary.)

RESULTS

Detection Thresholds. Table II shows detection thresholds for each of the three sites. Thresholds were computed by linear interpolation between those two distances at which 50% of the targets were detected. The thresholds ranged from 62.5 feet at the most difficult site (X) to 80.0 feet at the easiest site (Y).

For all three sites, the overall detection threshold was 72.6 feet. By linear interpolation, it can be assumed that at distances less than 56.1 feet, 75% of targets could be detected; at distances over 90.3 feet, only 25% of the targets would be detected.

TABLE II

Detection thresholds and 25-75% range at each of three evergreen rainforest sites.

Site	25% Detections (feet)	Detection Thresholds (50%) (feet)	75% Detections (feet)	n*
X	82.5	62.5	47.1	400
Y	91.9	80.0	54.6	400
Z	94.6	76.3	59.1	400
All sites	90.3	72.6	56.1	1200

* Number of observations

Figure 5. Target at 40 (top) and 60 feet (bottom) on radius III at Site Z.

Table III shows the percentage of targets detected at each of the eight distances. With slight variation from site to site, the eight distances adequately sampled the range of visual acuity for human targets in the evergreen rainforest sites. Overall, ninety-five percent of targets at the 40 feet distance were detected and only ten percent at the 100 feet distance. A total of 15 detections out of 150 opportunities was made at the 100 feet mark. Of these 15, nine were made on one site (Z)--and six of the nine were made on one unusually visible radius.

TABLE III

Percent of targets detected at each of eight distances at three evergreen rainforest sites.

DISTANCE (feet)	SITE X %	SITE Y %	SITE Z %	All sites* %
40	92	94	100	95
50	68	86	86	80
55	70	74	88	77
60	52	76	72	67
65	48	76	82	69
70	36	64	60	53
80	28	50	44	41
100	4	8	18	10

* 150 total observations for each distance

Figure 6 shows the same data in graphic form. The general conformation of the three functions is similar regardless of differences in their levels.

The relationship between detection probability and target distance was essentially linear with only minor reversals in the 55-65 feet range. For example, the combined (average) data for all sites were fitted by a straight line with a correlation coefficient* of -.993 (df=6; $P<1\%$). With this very high correlation, the standard error of estimate (σ_{yx}) reduces to only 2.91% detections. This means that on replication of this study, two-thirds of the newly obtained empirical detection values would probably lie within $\pm$ 2.91% detections from the predicted regression line. Similarly, 95% of the new detection values would probably lie within

* See Appendix D for definitions of statistical terms.

$\pm$ 5.9% detections ($2\sigma yX$) from the predicted regression line.

TABLE IV

Detection thresholds for each radius at three evergreen rainforest sites.

SITES	RADII I	II	III	IV	V	Mean (each site)
X	45.0	53.5*	85.0	87.5	59.5*	62.5
Y	84.0	91.1	88.0	70.0	52.5	80.0
Z	70.0	74.3	120.0**	80.0	65.5*	76.3
Mean (each radius)	66.3	73.0	97.7	79.2	59.2	72.6

* Threshold estimated by least squares
** Threshold estimated by linear extrapolation

Table IV compares detection thresholds for each of the five radii at each site. In those cases where there were no clearly defined thresholds, a least squares approximation was made from the function relating detection probability to distance. In one instance, at Site Z on Radius III, it was necessary to estimate the threshold point beyond the 100 feet distance because more than 50% of the targets were detected at all eight distances.

The purpose of these comparisons was to determine whether the three sites differed significantly with respect to the average threshold values and to determine whether there was a significant tendency for thresholds to vary as a function of horizontal target placement, i.e. did detections drop off systematically when targets appeared at the site peripheries (Radii I and V) as compared to the central radii? A repeated measures analysis of variance was performed on the data in Table IV. The analysis showed that the three sites did not differ significantly with respect to average detections ($F=1.45$; $df=2/8$; $P>5\%$) even though there was a 17.5 feet range between sites Y and X. The differences among the means for the three sites could have resulted from random differences obtained by drawing small samples from a larger distribution. The analysis also indicated no statistically reliable differences due to horizontal placement (radii) of targets ($F=2.84$; $df=4/8$; $P>5\%$), even though noticeably lower thresholds occurred on Radii I and V as compared to the central radii. The radii variations could also have occurred by chance sampling.

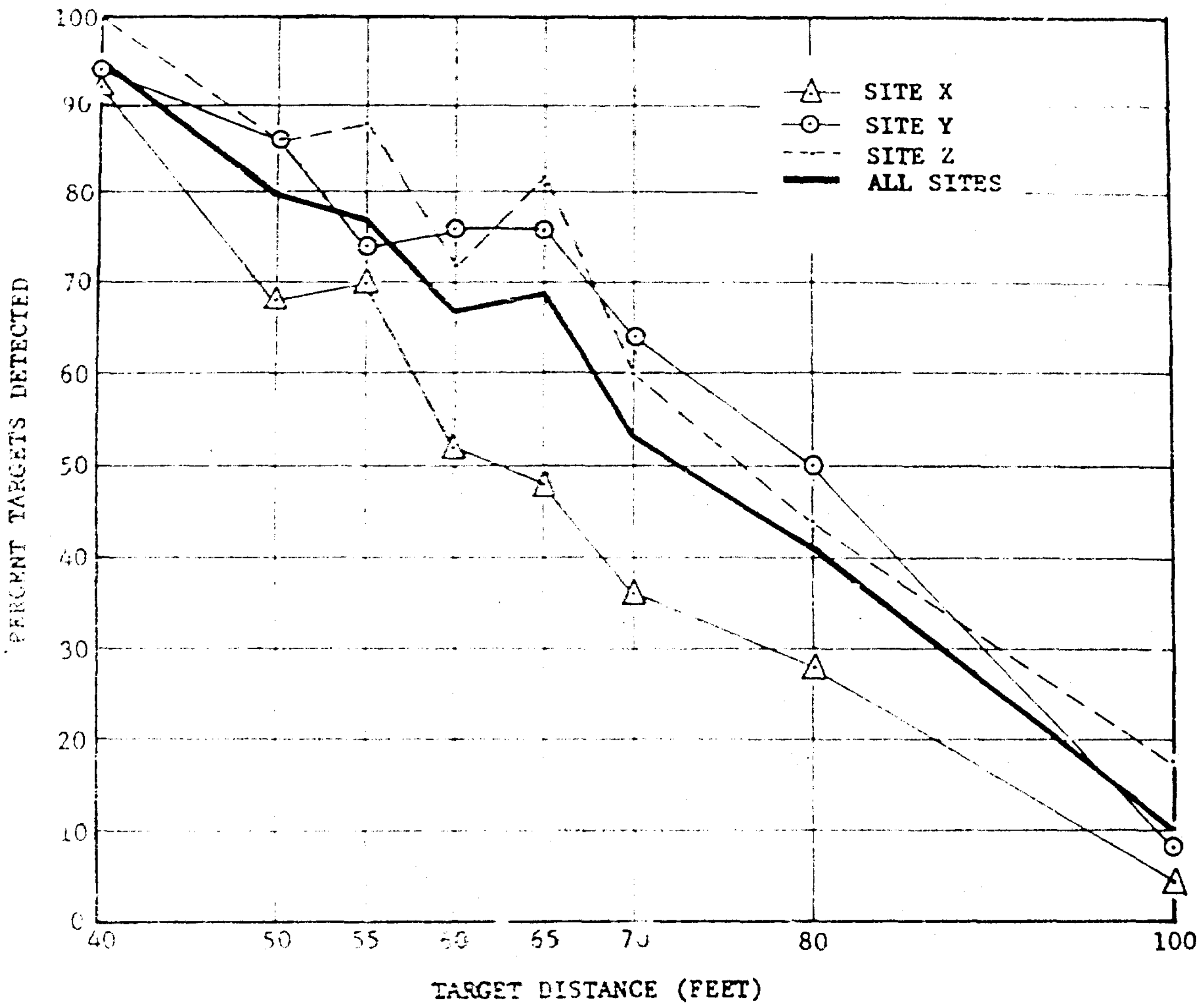

FIGURE 6. PERCENT OF TARGETS DETECTED AT THREE EVERGREEN RAINFOREST SITES.

Distance Estimation. In Table V, observer distance estimates of 738 detected targets are compared with the actual distances. Estimates are shown in terms of medians. A constant error of approximately 11 feet underestimation was made over all distances--mean of eight differences (E)-(D). The median estimates are also plotted in Figure 7.

Also shown in Table V are the semi-interquartile ranges of distance estimates. This statistic is an index of the variable error in distance estimates. There was only a slight tendency for variability to increase with distance of the detected target.

TABLE V

Actual distances compared with observer distance estimates for detected targets at three evergreen rainforest sites.

Actual Distance (D) (feet)	Estimated Distance (E) (Median)	Diff (E)-(D)	Semi-interquartile Range (Q)	No. of Estimates
40	27.0	-13.0	10.8	143
50	40.5	- 9.5	13.2	122
55	42.5	-12.6	15.1	114
60	46.7	-13.3	19.5	100
65	54.2	-10.8	17.3	103
70	60.0	-10.0	18.4	81
80	71.0	- 9.0	18.3	60
100	97.5	- 2.5	*	15

* Insufficient cases to compute Q

Individual Differences. The extent to which average detection thresholds may be relied on as relatively fixed quantities depends, of course, on the variation from O to O when tested at the same site under comparable conditions. Table VI shows thresholds for each O tested. The means and standard deviations are shown for each group of 10 O's. In general, there was little variation within sites except for Site Z, in which one very low threshold (53.1 ft) elevated the standard deviation.

Variability estimates based on these data apply to groups of O's similar to those tested in the present study. If extended to a larger military population, including those with visual

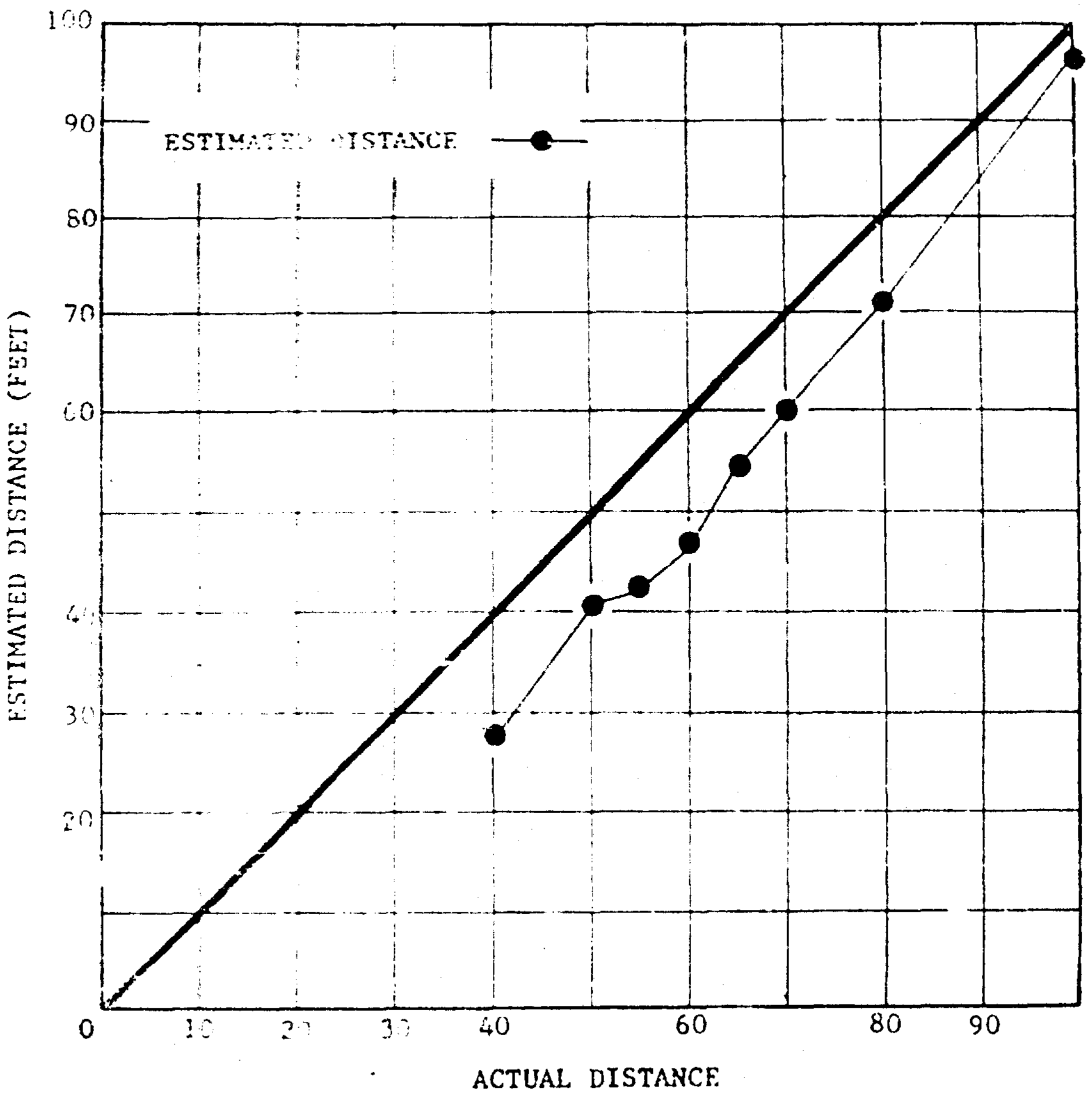

FIGURE 7. MEDIAN TARGET DISTANCE ESTIMATES OF 30 OBSERVERS AT THREE EVERGREEN RAINFOREST SITES.

defects, older, or less well motivated, the threshold would probably decrease and the standard deviation increase.

Detection Time. A stopwatch was used to record the time necessary to make a detection. These data are shown in Table VII. Mean detection times were similar from one site to another and showed no relationship with the detection threshold of the site.

For the three sites combined, mean times increased only gradually with distance from 40 feet to 80 feet. At 100 feet, however, there was a sharp rise.

TABLE VI

Detection thresholds for individual observers at three evergreen rainforest sites.

Site X		Site Y		Site Z	
Observer Number	Threshold (feet)	Observer Number	Threshold (feet)	Observer Number	Threshold (feet)
1	53.8	3	69.5*	2	53.1*
4	67.5	6	77.5	5	90.0
9	67.5	8	72.6*	7	75.0
11	58.8	10	75.0	12	90.0
15	57.5*	13	83.3	14	85.0
18	66.1*	17	85.0	16	72.9*
21	62.5	19	77.5	20	85.0
23	67.5	22	67.5	24	69.2
25	57.5	27	70.1*	26	72.5
28	67.5	30	87.5	29	67.5
Mean	62.6		76.6		76.0
Standard Deviation	5.0		6.6		11.0

* Threshold estimated by least squares

For example, it took nearly three times as long to detect targets at 100 feet than at 40 feet. Increased detection times probably were caused by the decrease in apparent target size, increased vegetative camouflage, and low illumination as target distances were increased.

Effects of Illumination. Measures of illumination were taken immediately before and after each test. Readings were taken at the observer's eye and at the 50 feet (midpoint) distance of each of the five radii. These measures are summarized in Tables VIII and IX. Both tables indicate a direct relationship between average illumination and the average detection threshold for a given site, i.e. Site X, the most difficult site, had average illumination levels only one-half as high as the other two easier sites.

TABLE VII

Time in seconds for target detection at three evergreen rainforest sites.

	Target Distance (feet)							
	40	50	55	60	65	70	80	100
Site X	28.3	29.6	32.3	35.6	33.3	39.5	33.3	*
Site Y	22.[illegible]	26.9	28.2	34.0	34.6	31.3	39.8	81.0
Site Z	16.9	14.0	17.1	31.6	26.9	33.4	41.9	51.0
Weighted Mean (Sec.)	22.4	22.9	25.4	33.5	31.2	34.0	39.0	61.5
Number Detections Per Distance	143	120	116	100	103	80	61	15=738

* Insufficient cases to compute mean

More striking than comparisons, however, are the low absolute illumination levels found at all sites*. At the observer, illumination ranged from a mean of 5.5 foot-candles to 17.0 foot-candles. Along the midpoint of the radii, illumination ranged from a mean of 4.3 foot-candles to 16.1 foot-candles. The lowest single level recorded was one foot-candle; the single highest level recorded was 45 foot-candles. A total of 58 readings at the one foot-candle level were obtained from a total of 360 readings.

Another type of analysis was made concerning illumination. The detection threshold for each O was correlated (Pearson product-moment) with the level of illumination (average of five radii) present on the site before and after his test. The correlation

* For reference purposes, the total illuminance on a fully exposed horizontal plane at sea level in clear weather is 10,000 foot-candles when the sun is directly overhead (7).

coefficient of .44 (df=28; $P<5\%$) reached statistical significance.

TABLE VIII

Illumination in foot-candles taken at eye level of observers before and after testing.

	Site X	N	Site Y	N	Site Z	N	Mean (all sites)	N
Start (0900)	5.5	(10)	17.0	(10)	12.2	(10)	11.6	(30)
End (1000)	9.6	(10)	10.9	(10)	16.1	(10)	12.2	(30)
Mean (each site)	7.6	(20)	13.5	(20)	14.2	(20)	11.8	(60)

No continuous measures of illumination were available nor were measures available at each of the 40 target locations, thus no "fine-grained" comparisons of detections with illumination levels were possible.

TABLE IX

Illumination in foot-candles taken at midpoint of each radius before and after testing (average of five radii).

	Site X	N	Site Y	N	Site Z	N	Mean (all sites)	N
Start (0900)	4.3	(50)	10.5	(50)	9.8	(50)	8.2	(150)
End (1000)	8.4	(50)	11.5	(50)	16.1	(50)	12.0	(150)
Mean (each site)	6.3	(100)	11.0	(100)	13.0	(100)	10.1	(300)

Effects of Observer Age and Experience. In an attempt to assess the effects of experience in target detection, both the age of the observer and length of Army service were correlated (Pearson product-moment) with detection thresholds. Detection thresholds were first statistically adjusted to rule out mean differences in difficulty among the three sites. The coefficient between age and thresholds was .04 (df=28; $P>5\%$), which was not statistically significant. The coefficient between length of Army service and thresholds was .08 (df=28; $P>5\%$), which was not statistically significant. The relatively restricted range of detection thresholds makes it very unlikely that any reliable associations with any external variables would be found.

Practice Effects. Finally, an analysis was made of practice effects. Individual detections were grouped into four blocks of 10 trials. The mean number of detections per observer for each consecutive block was computed. The mean actual distances within each block of ten trials differed due to target distance randomization and must be considered.

	1st 10 Trials	2nd 10 Trials	3rd 10 Trials	4th 10 Trials
Mean Number Detections	6.0	4.7	6.1	7.8
Mean Actual Distance (feet)	64.0	68.5	68.5	59.0

No evidence of a practice effect is apparent when the mean difficulty (actual distance) of the four blocks is taken into account.

DISCUSSION AND COMPARISON WITH JUNGLE VISION I

Before the reader proceeds to the following section, it should be remembered that the comparisons made are between results obtained in selected semideciduous sites during the dry season and selected evergreen rainforest sites during the wet season. The comparisons thus confound types of forests with climatic variables. Future studies are planned to replicate these observations in the semideciduous forest during the wet season and the rainforest during the dry season. At that time, the effects, if any, of the climatic variables can be assessed.

The only procedural differences between the two studies were the use of Infantry troops in Jungle Vision I and Artillery in Jungle Vision II, slightly different target distances, and the number of rest pauses given observers. None of these differences is believed to have introduced bias in the results. Otherwise, the research design, methodology and detailed procedures were identical, making the results directly comparable.

Table X compares selected results of the two studies. The overall threshold was higher, i.e. target detection apparently more efficient, in the evergreen rainforest setting than in the semideciduous forest. An analysis of variance, however, performed on the percent of detections* at separate target distances for Jungle Visions I and II revealed no statistically significant differences between overall detections for the Types of Forest ($F=0.48$; df=[illegible]; $P > 25\%$). The overall effects of target distances

---

* Percent detections subjected to inverse sine transformation prior to analysis of variance.

for both studies was, of course, highly significant ($F=130.00$; $df=5/20$; $P<0.5\%$). More important, the interaction between Type of Forest and Distance was marginally significant ($F=2.61$; $df=5/20$; $P<6\%$). The reason for the significance of this interaction was the distinct shapes of the two detection curves as a function of target distance. This difference is discussed more fully in the succeeding paragraph. Thus, these results indicate, to date, that the semideciduous and the evergreen rainforests represent only one population of vegetation insofar as 50% threshold detectability is concerned. These results are based on data from 60 persons constituting almost 2400 separate observations. There appears to be a balance between the dense eye-level vegetation of the semideciduous forest and the low illumination levels of the evergreen rainforest and a similar balance between the higher illumination levels of the semideciduous forest and the more sparse eye-level vegetation of the evergreen rainforest. These balances could account for the test results, which indicate no practical differences between the two types of forest in average detection difficulty.

Figure 8 compares the smoothed detection probability functions for Jungle Visions I and II. The differences in conformation appear more important than the comparison of overall thresholds. Detection probabilities for the semideciduous forest decreased gradually up to 55 feet, then dropped sharply up to 75 feet where the rate of change again became less accelerated. These inflections resulted in an inverted S-shaped or ogival function. The rainforest function, on the other hand, was well fitted by a straight line. Both functions would intercept the abscissa at approximately 110 ft; this distance probably represents a good estimate of the absolute limits of target detectability in both types of forests. Since each of the two functions has been computed from three replicates each, and since each of the six replicates individually resembles its combined counterpart in Figure 8, the functions probably represent valid intrinsic differences. Thus, it is concluded that even though detection difficulty between the two forest types did not differ significantly, the probability of detecting targets at discrete distances differed substantially, with the semideciduous forest becoming a great deal more difficult between the 65 to 100 feet distances. It is also concluded that even though the functions differ, the observer in either type of forest is in a horizontal "visual envelope" with an absolute limit to target detection at distances of 100-110 feet in typical vegetation. It may be noted parenthetically that the S-shaped function is very similar to those obtained in many psychophysical studies carried out in the laboratory (11), and specifically to those which relate detection probability with visual angle (target size). The reasons for the differences in functions cannot be obtained from the empirical data at hand.

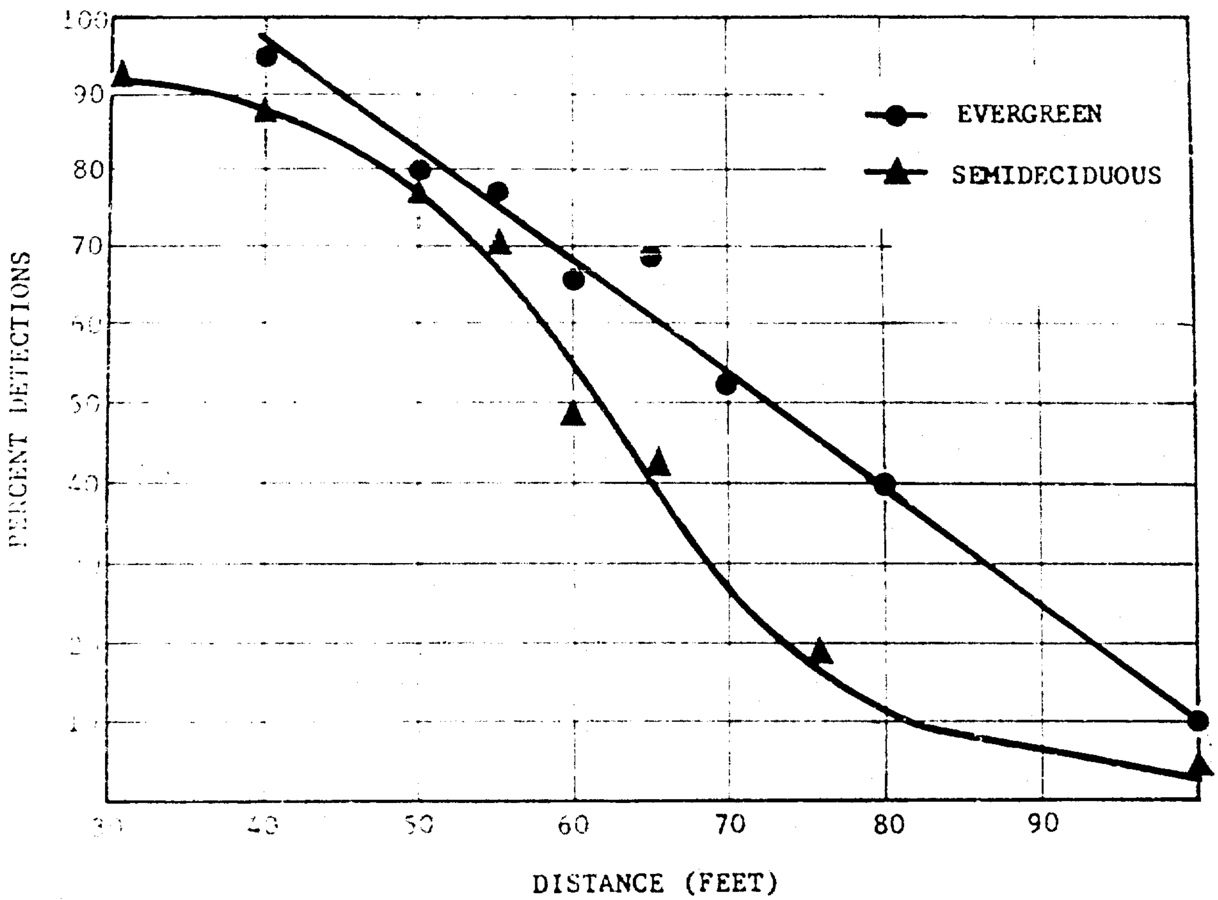

FIGURE -. COMPARISON BETWEEN TARGET DETECTION PROBABILITIES IN TROPICAL SEMIDECIDUOUS AND EVERGREEN FORESTS.

TABLE X

Comparative Summary of the Results of Jungle Vision Studies I and II

		Semideciduous	Evergreen Rainforest
1.	Total observations:	1198	1200
2.	Detection thresholds:	Clayton - 61.0 ft	X - 62.5 ft
		Albrook - 70.3 ft	Y - 80.0 ft
		Empire - 52.5 ft	Z - 76.3 ft
		All sites 59.6 ft	All sites 72.6 ft
3.	Percent detections: 40 ft	88%	95%
	50 ft	77%	80%
	55 ft	70%	77%
	60 ft	48%	76%
	65 ft	42%	69%
	100 ft	4%	10%
4.	Function relating detection probability to target distance (See Figure 8):	S-shaped	Straight line
5.	Ambient illumination:		
	a. Mean foot-candles at O (morning):	232 fc	12 fc
	b. Mean foot-candles on radii (midpoint morning):	128 fc	10 fc
	c. Correlation -- illumination vs detection thresholds:	r=.04	r=.44 (Sig)
6.	Intraforest variability (three means each standard deviation):	=7.3 ft	=7.5 ft
	Interforest variability (semideciduous vs rainforest - two means only):	6.5 ft	
7.	Distance estimation (mean underestimate):	-10 ft	-11 ft
8.	Detection time:	Increased by factor of 2.6 from 40 to 75 ft	Increased by factor of 1.7 from 40 to 80 ft
9.	Observer attributes:		
	a. Correlation O's age vs thresholds:	r=.18	r=.04
	b. Correlation length service vs thresholds:	r=.27	r=.08
10.	Practice effects:	None	None

In general, there are four factors which influence the detectability of any target: (1) target size, (2) contrast of target with background, (3) search time available to observers, (4) illumination level--and in the present studies--(5) intervening vegetation. Factors (1) and (3) were identical in the two studies and may be ruled out; factor (2) was very similar in the two studies; thus, illumination levels and intervening vegetation remain as the most likely sources of the difference. Table X shows that mean illumination levels ranged from 13 to 20 times higher on the semideciduous sites than on the rainforest sites. Furthermore, the significant correlation between illumination level and detection thresholds present in the rainforest data and absent in the semideciduous data affords some admittedly gross evidence that illumination played a greater role in Jungle Vision II. However, since there is no numerical index of vegetation density, it is not possible to parcel out the relative contributions of vegetatation and illumination in the two studies--nor is there to the authors any readily apparent reason why detection probabilities should describe a straight line in the evergreen rainforest. Stiles (1) has suggested that target shape plays a greater role in detection at closer distances, giving away in importance to detail, color, and texture as distance increases. If this is true, then lowered illumination in the rainforest may interact in some manner with the latter three factors to account for differences in detection functions. In summary then, the two functions differ, and the authors speculate that the difference is primarily caused by different illumination levels in an undetermined manner.

Earlier in this report it was mentioned that one purpose of replicating sites within forest types, other than a better sampling of vegetation, was to estimate the intrinsic variability of personnel detection within and among the major types of tropical vegetation. Indeed, the entire worth of studies such as these depends on how much the results can be generalized; and variance restricts generalizations. Some comparisons are made in Table X. Estimates of intraforest variability are given by computing standard deviations of the three site means obtained within a given type of forest. Based on only three means each, there is very little difference in the variance within forests. Based on only two means, it can be seen that the variation between types of forest is less than the average variation within forests. These findings lead to a tentative conclusion that the major forest types, at least as represented in the Canal Zone, are not distinct entities with respect to 50% visual threshold difficulty. More replications will be necessary before a firm statement may be made. More important, however, is the fact that standard deviations in 7-8 feet range are sufficiently small to allow generalized statements concerning target detections in tropical forests, regardless of the particular geographic site selected.

The constant errors of underestimation of target distance were found to exist for both types of forest, were approximately equal, and seem to be fairly constant for all target distances. Since these data are based on approximately 1400 estimations, the presence and magnitude of these errors probably represent a reliable effect. In general, stereoscopic vision is degraded by the absence of the well known cues for the binocular perception of depth, including lack of color contrast, interposition of objects, and homogeneous texture of the visual surroundings. Homogeneity of vegetation is marked in both types of forests Interpositioning of objects, in this case vegetation, between observer and target is also attenuated extremely by the thickness and sameness of intervening vegetation.

Detection times increased with target distance in both studies. This was an expected effect due to the simple fact that apparent target size and clarity of outline are reduced as distance is increased. The quantitative extent of the effect was of major interest. There was little difference between detection times in the two types of forest. It will be remembered that fewer targets were detected at the longer distances in the semideciduous forest; however, it seems that if a target is detectable, it takes about the same amount of search time in either forest. These data are based on nearly 1300 recorded search times.

None of the correlation coefficients computed between detection thresholds versus age or experience was significant in either study. Several considerations enter here. Both groups represented restricted populations with respect to visual acuity because of preselection, this probably led to a restriction of variability in detection thresholds. The groups were also fairly homogeneous with respect to age and length of service. All of these considerations serve to restrict the range of both variables being correlated, consequently reducing the probability of obtaining significant covariation.

Practice effects were not found in either study. This finding is perhaps explained by the fact that the task is simple and, therefore, easily learned; furthermore, the task is based primarily on simple visual acuity which is not a learnable skill.

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APPENDIX A

Order of Target Presentation

Distance (feet)	Radius				
	I	II	III	IV	V
40	14	9	17	5	28
50	31	13	3	36	33
55	35	38	40	8	18
60	25	29	10	22	21
65	2	34	37	30	39
70	15	12	27	24	1
80	7	20	32	4	16
100	23	11	26	19	6

APPENDIX B

Sequence of Observers Tested
at Three Different Sites

Site X	Site Y	Site Z
1	3	2
4	6	5
9	8	7
11	10	12
15	13	14
18	17	16
21	19	20
23	22	24
25	27	26
28	30	29

APPENDIX C

Instructions given to the O by E prior to the start of each test session.

"We are trying to find out how well you can detect targets through the foliage. You will see one of these fellows (demonstrates) standing up facing you between nine o'clock (point) and three o'clock (point) at different distances from you. There will be only one target at a time. When I give you the signal, you are to stand up in this marked box (point) and search for the target. You may crouch, kneel, or even lie down, providing you don't move your head out of the box (demonstrate). If you spot him, point in his direction and tell me how far away you think he is. You will have two minutes to find him. If you don't spot him in the time limit, I will turn you around and score a miss. If you think you see him, but are doubtful, go ahead and guess. There will be 40 trials in all, and the test will last about an hour and a half. Are there any questions?"

APPENDIX D

DEFINITIONS OF STATISTICAL SYMBOLS

F-ratio:	This ratio is derived from the analysis of variance. The analysis of variance yields the probability that the variation in a set of means may be attributed to random sampling from a common, normally distributed population.
Probability (P):	This symbol refers to the level of confidence which may be placed in the statistical significance of values derived from many different types of statistical tests and measures.
Degrees of freedom (df):	Degrees of freedom are related to the number of observations entering into a particular test of significance. To some extent, the degrees of freedom determine the level of confidence placed in the results of the analysis.
Semi-interquartile range (Q):	This is a measure of variation which includes one-half of the middle 50% of a normal frequency distribution. It is ordinarily employed as a measure of variation when the median is used as the measure of central tendency.
Standard deviation (σ):	This is a measure of the variability of individual values in a frequency distribution around the mean value.
Standard error of estimate (σyX):	A measure of the goodness of fit of empirical data around a predicted function such as a regression line.
Coefficient of correlation (r_{xy}):	The Pearson Product-Moment correlation coefficient is a measure of the extent to which two variables tend to vary together. A coefficient of ".00" indicates the variables fluctuate independently of each other. A coefficient of "1.00" indicates that the variables are perfectly related.

Median: The midpoint of a series of numerical values; it represents a point on a continuum rather than an algebraic average.

Weighted mean: This is the grand mean of a series of individual means weighted by the total number of observations entering into the computation of the individual means.

Inverse sine transformation: A transformation frequently applied to percentage values prior to analysis of variance to reduce correlation between means and variances.

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1

a. View of Site X from Observer's position

2

b. View of Site Y from Observer's position

3

4

Figure 3. Views of three evergreen rainforest sites

b. View of Site Z from Observer's position

c. View of Site Z from Observer's position

6

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